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CHARACTERIZATION OF SOLID PARTICLE SCREENING AEROSOLS USING A TEST CHAMBER

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Characterization of screening aerosols often requires dissemination of the aerosol into a confined chamber. This report describes such a chamber and the appropriate instrumentation and data collecting apparatus that is involved with testing within chambers. Dissemination techniques are also described as well as methods for concentration measurement. Keywords Test chambers

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PREFACE

The work described in this report was authorized under Project No. 1C162622A552, Smoke and Obscurants. This work was started in January 1986 and continues as of July 1990.

The use of trade names or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

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1. INTRODUCTION

Characterization of screening aerosol materials often requires dissemination and examination of the aerosol within a controlled environment. The contained aerosol can then be studied and measured without concern for climatic conditions. In addi⁚ion, less material is required for the study; therefore less waste is generated. This report describes a controlled environment, a test chamber, with devices and systems that measure and characterize the aerosol both physically and electromagnetically.

?. DESCRIPTION

The test chamber is constructed of 1/4-in. Plexiglas sheets, which are joined, glued, and sealed together to form a rectangular box 3.8 m long, 0.92 m high, and 0.92 m wide. At one top corner of the box, an exhaust port is connected to a filtered exhaust system. With the control damper open and the chamber sealed, a negative pressure of 3/4-in. of water is present within the chamber. A 2-ft by 2-ft removable door is cut into one long side of the chamber to allow easy access to the inside of the chamber. During operation, this door is sealed against strips of foam insulation with 12 clamps. Two stirring fans are mounted on the floor of the chamber, one near the center and the other at one end of the chamber directed toward the center of the chamber. These fans stir the aerosol cloud during a test and assure that the cloud is evenly distributed throughout the chamber, which has been substantiated by simultaneous concentration measurements at three points along the chamber's length.

3. INSTRUMENTATION

Electromagnetic screening efficiency of the aerosol cloud is measured by four electronic devices mounted at the ends of the chamber. The devices were selected to cover the electromagnetic spectrum from the visible region to the millimeter range and consist of sources and detectors that transmit and measure the intensity of electromagnetic beams through the chamber. In the visible region, an HeNe laser that transmits a beam at 0.63 μm wavelength is mounted at one end of the chamber and aimed at a photoelectric detector at the opposite end. A CO_2 waveguide laser, transmitting at a 10.6 μm wavelength, together with a pyroelectric detector, measures intensity through the chamber in the infrared portion of the spectrum. Intensity in the millimeter region is measured by two radar transmissometers operating at 94 GHz (3.2-mm wavelength) and 35 GHz (8.4-mm wavelength). The two radar devices are similar; both the source and detector are mounted at one end of the chamber, and adjustable aluminum plates at the other end of the chamber reflect the transmitted radar beam back to the detectors. Thus, the radar beams pass through the chamber twice.

A schematic drawing of the test chamber and instrumentation is shown in Figure 1. To minimize attenuation of the signal intensity due to the Plexiglas thickness, portholes have been cut out of the ends of the chamber where the various beams enter and leave it. These ports are covered with plastic film to confine the aerosol within the chamber and to allow for easy changing of the port windows if they become coated with aerosol.

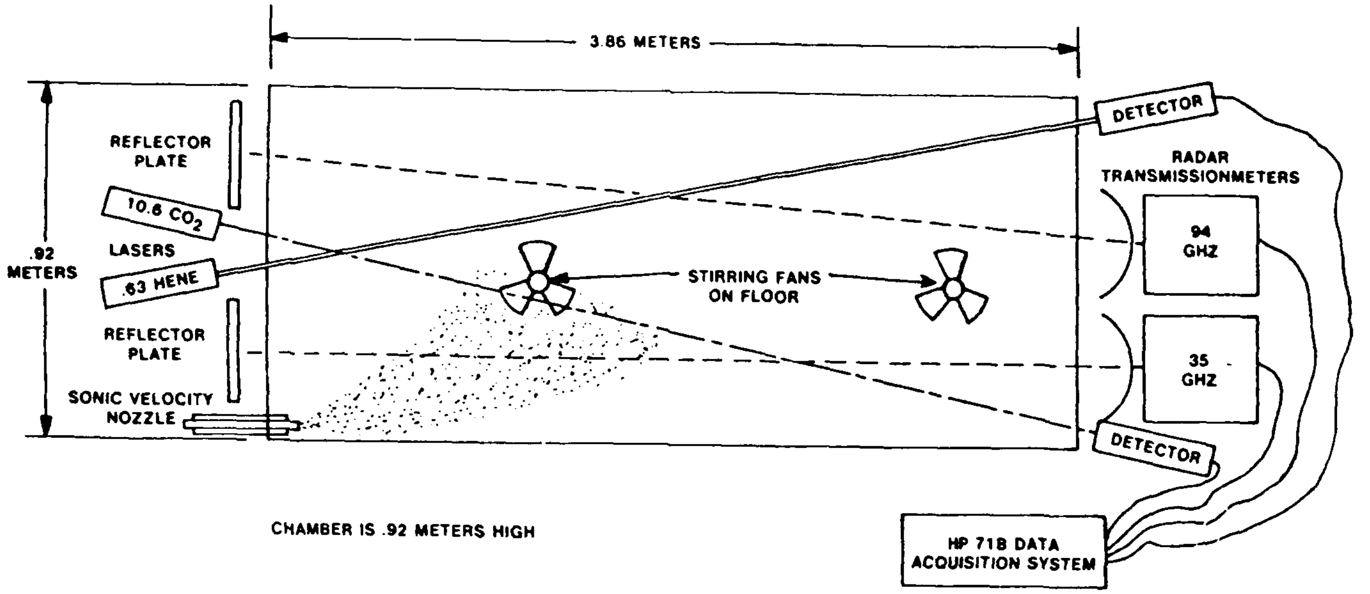

Figure 1. Schematic Diagram of Test Chamber

4. INSTRUMENTATION OUTPUT

The detectors for each device are output to independent amplifiers, which convert the measured beam intensity into voltages displayed on a strip chart recorder. These output voltages are also measured by a Hewlett-Packard (HP)(Rockville,MD) Model 3421A Data Acquisition System, controlled by an HP Model 71-B Computer. Data from each test in the chamber is saved on an HP Model 9114B Disk Drive, and the calculated results are printed on an HP Thinkjet Printer. The actual computer program that controls the data acquisition, calculation, and printout of results will be described later.

5. DISSEMINATION

Dissemination of candidate screening aerosols into the test chamber can be done by either mechanical or pneumatic devices. Some of these are described elsewhere.[1] The device most used in this chamber is a sonic velocity nozzle, which is diagrammed in Figure 2. This nozzle was designed to deagglomerate powders at a

[1] Riley, E.R., and Wright, R.J., Solid Particle Aerosolization for Smoke Chamber Studies, CRDEC-TR-057, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, April 1989, UNCLASSIFIED Report.

carrier air pressure of 40-60 psig, is an excellent dissemination device for chamber work, and can be operated as low as 5 psig. The carrier gas, usually compressed air, exits the nozzle through an annullar opening around a 1/4-in. tube, which passes all the way through the device. The exiting compressed air, which is moving at sonic velocity when the carrier gas pressure is greater than 40 psig, creates a negative pressure within the tube, and test material is drawn into the tube by aspiration, then deagglomerated and disseminated by the shear forces at the tube outlet. The sonic velocity nozzle has been used to disseminate a wide range of materials, from submicron sized powders to fibers up to 1/8-in. long.

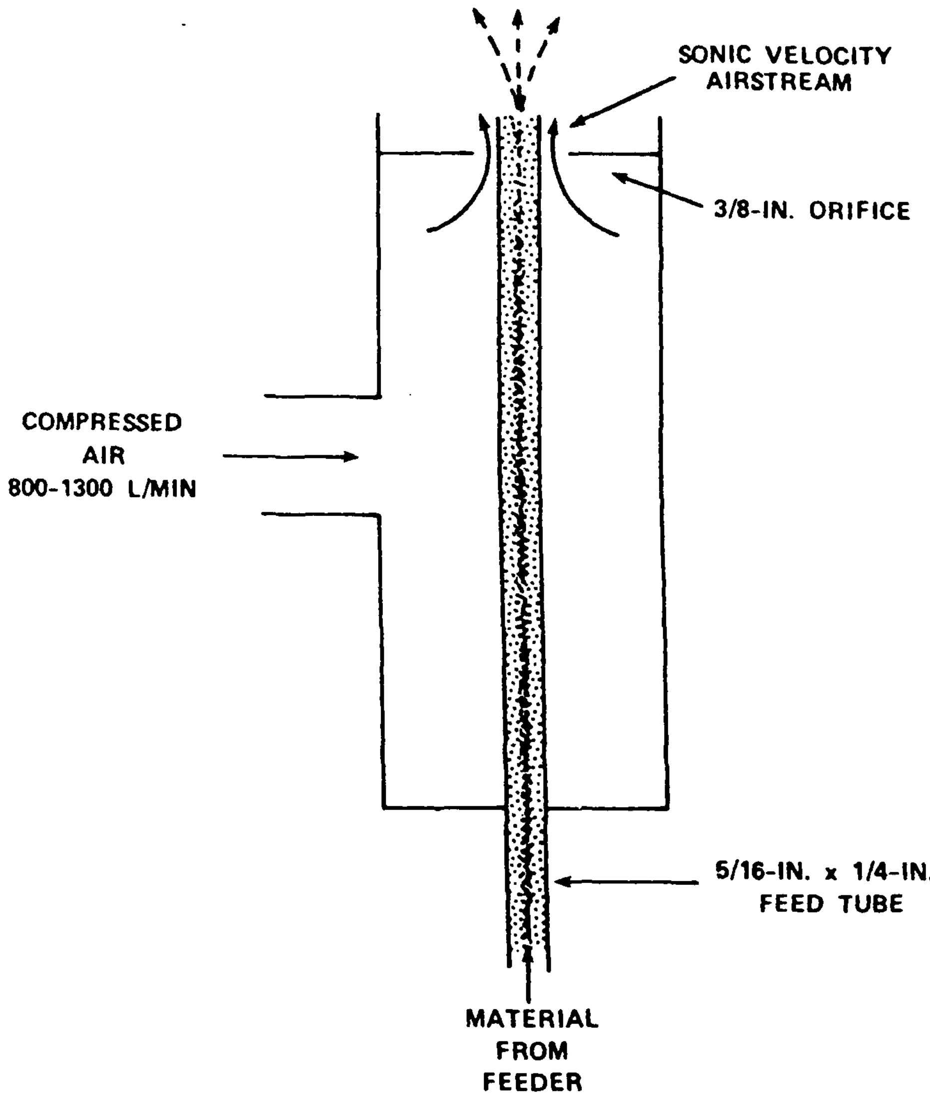

Figure 2. Schematic Diagram of Sonic Velocity Nozzle

To prevent chamber overpressure due to the large quantity of air coming out of the sonic velocity nozzle, the exhaust damper in the chamber vent is opened during dissemination and then closed during measurements of the aerosol cloud. The sonic velocity nozzle is mounted at one end of the chamber and aimed to disseminate material down the length of the chamber.

6. SAMPLING

Measuring the aerosol concentration within the chamber is normally done using a mass aerosol filter technique in which the filter weight, the aerosol-loaded filter weight, the flow rate through the filter, and the sampling time are measured. This method works well for small aerodynamic diameter particles (D_E <15 μm). However, when characterizing large particles (D_E >15 μm), measuring the concentration by a filter sample is not very accurate, either because the particles are too large to follow the streamlines into the filter opening or because the particles bounce off or are blown off the filter during or after sampling. Fortunately, an alternate method to obtain aerosol concentrations of large aerodynamic diameter particles [geometric optics inversion (GOI)] is available.[2] This technique uses the transmittance in the visible region to calculate the aerosol concentration, but the technique is limited to particles that are uniformly sized, convex, and randomly oriented, and having diameters larger than the HeNe laser wavelength of 0.63 μm.

To aid in examining the aerosol and to provide further physical documentation of the disseminated material, samples from within the aerosol cloud are collected on sticky tape for optical and/or scanning electron microscope photographs.

7. MATERIAL CHARACTERIZATION

Measuring the screening efficiency of a material involves calculating the extinction coefficient (α) which involves determinating transmittance (T), pathlength (L), and concentration (C). The transmittance (T) is the ratio of intensity of a beam through an aerosol to the intensity when no aerosol is present. Using the electromagnetic devices described in Section 3 above, this is a straightforward, continuous, real-time measurement at any wavelength of incident energy. The pathlength (L) is the distance that the incident energy beam travels through the aerosol cloud. Aerosol concentration (C) is calculated using either filter sampling or the GOI method described in Section 6.

Deriving the expression for (α) starts with equation 1:

$$I = I_0 e^{-\alpha CL} \tag{1}$$

By dividing equation 1 by the intial intensity (I_0) , and taking the natural log of both sides of the equation, we get equation 2:

$$\ln \left(\frac{I}{I_0} \right) = -\alpha CL \tag{2}$$

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[2] Wright, R.J., Embury, J.F., and Anderson, D.H., Real-Time Concentration Monitoring of Large Aerodynamic Diameter Fiber Aerosols Using the Geometric Optics Inversion Technique , CRDEC-TR-194, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, June 1990, UNCLASSIFIED Report.

By definition, T is equal to $I \,/\, I_0$. The negative sign on the right side of equation 2 is eliminated by inverting the contents of the log term. The result is equation 3:

$$\ln\left(\frac{1}{T}\right) = \alpha CL \tag{3}$$

Solving for α we get equation 4:

$$\alpha = \frac{\ln\left(\frac{1}{T}\right)}{CL} \tag{4}$$

The units of α are in m^2/g.

The transmittance (T) is measured at each wavelength; L is usually the chamber length, but in the case of the radar transmissometers mentioned in Section 3, L is twice the chamber length. The concentration measurement (C) depends on the type of material being examined. If the aerosol cloud is composed of polydisperse particles, with an aerodynamic diameter <15 μm, three filter samples are taken, and the initial concentration of the cloud is then calculated. If the aerosol cloud consists of monodisperse, convex, large aerodynamic diameter particles, randomly oriented, then the GOI technique is used to calculate C.

8. DATA COLLECTION, CALCULATION, AND DISPLAY

As mentioned earlier in Section 4, data collection is under the control of a computer, which first measures the voltages of each detector when all of the energy beams have been blanked or blocked off. The computer then "tells" the operator to unblank all devices and measures the nonaerosol intensity through the chamber. The blanked or "zero" readings are subtracted from each voltage measurement taken later in the test, and the nonaerosol, or 100% readings are the values for I_0 in equations 1 and 2 above.

Material is then disseminated into the test chamber, and the program rapidly takes data (the aerosol, or attenuated, intensity I) sequentially from each detector. The data acquisition system, which is actually measuring the voltages out of each detector, can measure and store about five variables per second. For each wavelength, the data and the elapsed time since the start of data collection are stored in the computer's memory in arrays in ratios of aerosol intensity (I) to nonaerosol intensity (I_0).

When the data collection is complete, the computer program smooths the data, using a 13-point smoothing subroutine, and if the GOI technique is being used either calculates C, and subsequently the extinction coefficients, or "asks" the operator to input the filter sample weights, which are then used to calculate C and α. The transmittance data versus time for each wavelength is stored on a floppy disk for later examination, if necessary. The data is also printed out showing T and α versus time.

At this point, the computer "asks" the operator for the weight of material that was disseminated and calculates the yield (initial concentration times the chamber volume all divided by the mass disseminated), which is the amount of the disseminated material that actually became aerosolized. The resulting number is between 0 and 1. For example, a yield of 0.5 indicates that 50 % of the material was aerosolized and contributed to the measured concentration. Although it is somewhat material dependent, the yield number is more a measure of the efficiency of the disseminating device.

The transmittance and extinction data can also be plotted to provide a graphic display of the aerosol cloud effects. These plots, the photographs of the disseminated material, and the calculated extinction coefficients and yields provide a relatively complete characterization of the screening material and can be compared to similar tests of other materials to determine the most efficient screening aerosol at various wavelengths.

Examples of transmission data collected using the test chamber and instrumentation are displayed below. The three types of material characterized in this test chamber are:

a. A small diameter powder

b. A conductive flake

c. A conductive fiber

All of these materials were disseminated successfully by the sonic velocity nozzle (Section 5). Concentrations for the powder and flake materials were measured using filter samples; whereas, concentrations for the fiber material used the GOI technique mentioned in Section 6. Values of material concentration in the chamber ranged from 50 to 300 mg/m^3, and the transmissions that appear in Figures 3, 4, and 5 will depend on the material concentration in the chamber.

8.1 *Powder Data.*

Typical transmission data for the powder material appears in Figure 3, which displays the responses at each measuring wavelength over time. Time zero is the point where dissemination is complete and data collection begins. A typical yield (Section 8) for this powder is 71%. Note in Figure 3 that there is a large attenuation (low transmission) at 0.63 micron (HeNe laser) but no attenuation of the infrared (IR) or 94 GHz signals. Also note that the slope of the transmission is relatively flat, indicating a very small settling velocity. (The Stokes settling velocity is about 0.0013 cm/s.)

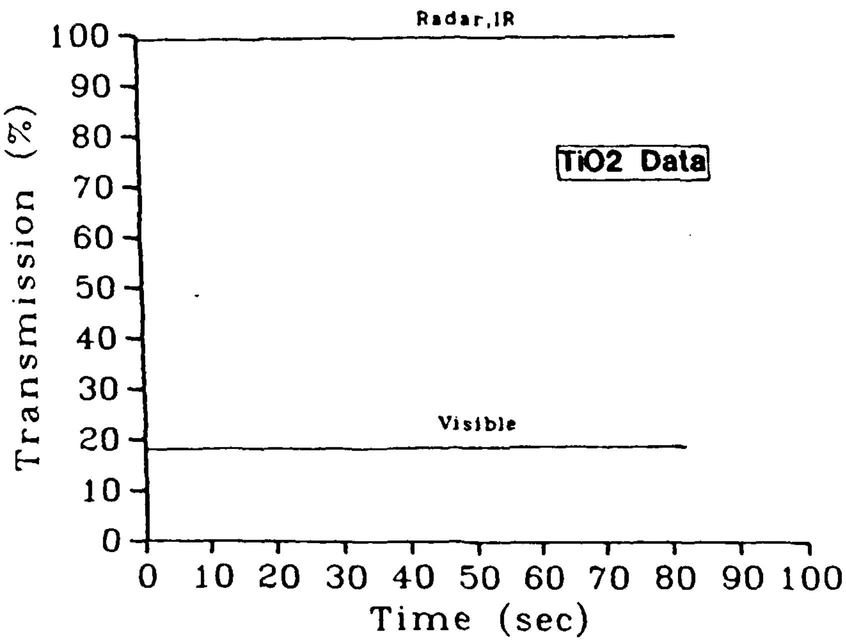

Figure 3. Transmission Data for a Typical Powder

8.2 *Flake Data.*

Typical transmission data for the flake material appears in Figure 4, which displays the responses at each measuring wavelength over time. Figure 4 shows that the flake material attenuates in both the IR and visible regions but not in the radar region. The yield for this material is roughly 95%; its Stokes settling velocity is around 1.5 cm/s.

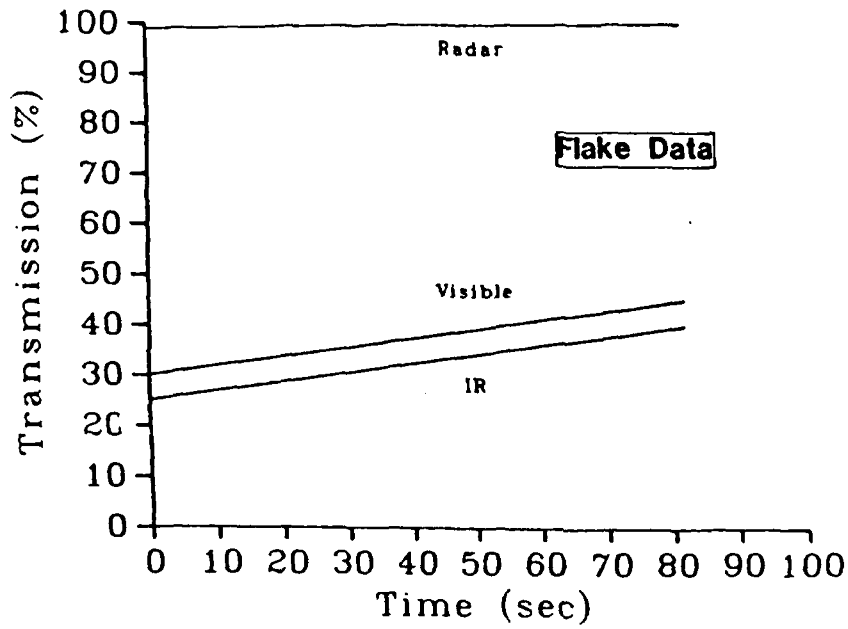

Figure 4. Transmission Data for a Typical Flake Material

8.3 *Fiber Data.*

Typical transmission data for the fiber material is shown in Figure 5, which also shows that the high attenuation at 94 GHz is due to the presence of the conductive fiber cloud. The figure also shows that IR attenuation is negligible. The visible attenuation, measured by the HeNe laser, is also very small; but when characterizing fiber material using the GOI method (Section 6), the laser beam is reflected back and forth via mirrors at either end of the chamber to provide a measurable attenuation sufficient to insert into the GOI concentration calculation. The yield for fiber material is usually around 30% when the sonic velocity nozzle is used as the dissemination device. As seen in the time-rate-of-change of the radar transmission data in Figure 5, the settling velocity of this material is about 2.2 cm/s.

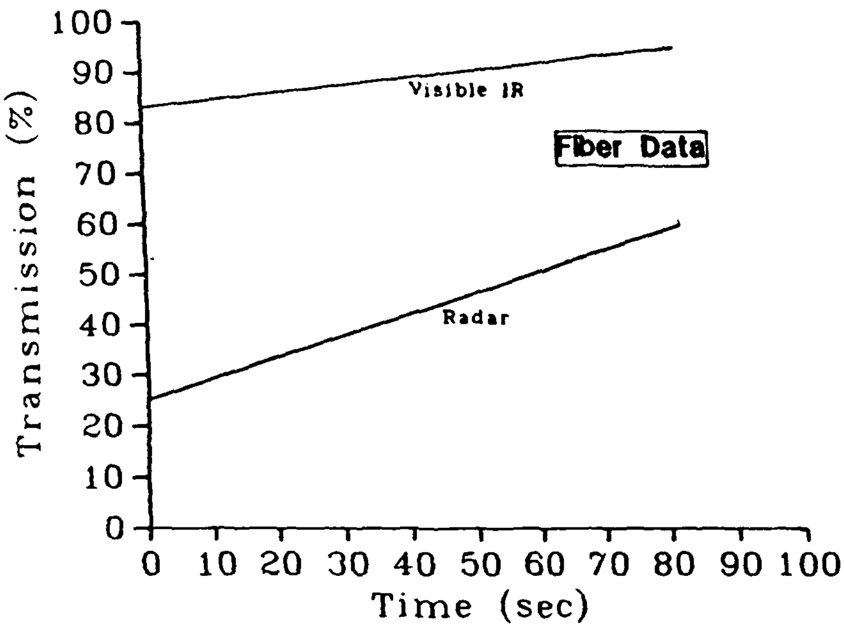

Figure 5. Transmission Data for a Typical Conductive Fiber Aerosol Cloud

9. CONCLUSION

This test chamber provides an inexpensive, rapid, and effective facility to characterize solid particle screening aerosols with a minimum expenditure of material and therefore a reduced amount of waste. It also reduces environmental effects on the aerosol cloud and eliminates aerosol effects on the environment.